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La Serreta endokarst (SE Spain): a sustainable value?

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Abstract: La Serreta endokarst (SE Spain), which UNESCO declared a World Heritage Site in 1998, was considered a sanctuary with cave art and one of the most important archaeological sites in the Mediterranean region for both the remains it hosts and the spectacular karstic landscape at the site.

To coincide with the 40th anniversary of its discovery, the La Serreta cave-chasm was adapted for public use with the intention of showing visitors the remains, which date back to prehistoric times. The solution included attempts to minimize contact with the valuables in the cave in order to alter the existing remains as little as possible and to make good use of the magnificent interpretative conditions of such a unique place by showing the spectacular views over the Los Almadenes canyon, where the Segura River flowed, which is now a viewpoint over the void.

In order to determine the sustainability of the endokarst, the Karstic Sustainability Index (KSI) was applied as a standard measure of sustainable development practices in karstic environments, which employs indicators for the three domains: use of social, economic and environmental resources. By applying this index, La Serreta endokarst was found to be progressing towards the sustainable management of karst resources.

Keywords: algae; archaeology; biodeterioration; cave paintings; cyanobacteria; endokarst; karst sustainability index (KSI)

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INTRODUCTION

Ecotourism has become the most important economic activity in many karstic areas. Indeed, approximately 20 million people visit different tourist caves every year worldwide (Lobo et al., 2010a). This tourist interest in caves has shown a growing trend in recent decades. Hence, the quantification of the world's caves open to tourists has become a hard task, based on very few references which cite some 750 show caves around the world (Lobo et al., 2010b).

A tourist cave houses a series of aesthetic, cultural or natural values, which mankind can enjoy and make full use of, for example, in organized business activities (Rivas et al., 2004). Tourist caves which focus on cultural contents tend to house a valuable representation of cave paintings, as well as the remains of former human presence and prehistoric occupation (Cigna, 1993). From the quantitative perspective, however, visits to these caves cannot be compared to other caves whose aesthetic character stands out, and the singular value of these resources makes them highly distinguishable inland destinations. In such caves, attention is mostly paid to didactic and scientific contents, which are ideal for tourist demands of an academic and cultural nature (Huppert et al., 1993). It is to this type of tourist cave that La Serreta endokarst belongs, which was declared Heritage of Cultural Interest by the Spanish Historic Heritage Law of 1985; it was later declared a World Heritage Site by UNESCO in 1998, to become part of the Spanish Mediterranean cave art series (Ministerio de Cultura, 2005).

Seminaturalistic schematic cave paintings dating back to the post-paleaolithic period (5000-4000 BC) are conserved on the walls of La Serreta. Inside the cave, Argaric (early Bronze Age culture, 1700-1300 BC) utensils have been found, as have the remains of two Roman houses (300 AD), which are considered to be the few Roman abodes known in caves, plus evidence that supports its use as a refuge for cattle from the Islamic Middle Ages (10-12 centuries) until the 20th century (Salmerón, 1999). These different levels of cultural occupation convert La Serreta cave-chasm into a sanctuary of cave paintings, a Neolithic habitat and a Late Roman Empire refuge. This endokarst is situated in a protected natural area in the upper course of the River Segura as it passes through the Murcia Region, SE Spain. This place has been proposed as a Site of Community Importance and forms part of a special protection area for birds, which has been included in Natura 2000, a large network of natural areas in Europe.

Furthermore, the management of a tourist cave run by a local organization positively benefits the municipality's socio-economic development, provided that its implementation focuses on creating jobs locally and on generating business activities associated with tourism in caves. This is particularly important at the local level if we consider that the majority of caves belong to localities with less than 7000 inhabitants (Rivas et al., 2004). The main problem of tourist management of caves with significant cultural contents lies in their fragile conservation, particularly in relation to modifications of cave micro-climates and of the rock supporting cave paintings (Villar, 1993). In general, the efforts that have been made to make the public aware of the extraordinary prehistoric findings in caves have led to mistaken cave management from the very start (Calaforra et al., 2003). To create ideal conditions to conserve these caves, specific measures for visits need to be taken, which consist in establishing their daily and seasonal limits (visitors capacity; Cigna, 1993) or in defining special protection areas. Restrictions of visits imply that the tourist demand exceeds the supply; therefore, economic interests as opposed to characteristic sustainable caves management criteria and objectives may come into play (Fernández-Cortés, 2005).

In addition, karst features are highly susceptible to human influence. Removing tree cover, improper waste disposal, excessive ground water pumping, opening or closing cave entrances, quarrying, filling in sinkholes and modifying superficial drainage patterns, just to name a few, negatively impact karst terrains. In 2005, van Beynen and Townsend created a standardized and hierarchical Karst Disturbance Index (KDI). Their index provides researchers with a tool to measure risk, and to compare and contrast the degree of karst disturbance in a given region. Prior to this publication, no method for holistically comparing, measuring, and contrasting karst disturbance existed.

The KDI is not the only environmental index that can be applied to karst environments. DRASTIC (Depth to water, net Recharge, Aquifer media, Soil media, Topography, Impact of the vadose zone, hydraulic Conductivity of the aquifer) is a commonly used ground water vulnerability index. It developed risk rankings for aquifers using physical environmental parameters, such as hydraulic conductivity, depth to recharge and topography, among others (Aller et al., 1986). Two more recent additions to these types of ground water vulnerability indices are FAVA (Florida Aquifer Vulnerability Assessment) by Arthur et al. (2007) and EPIK (Epikarst, Protective cover, Infiltration conditions, Karst network development) by Doerfliger et al. (1999). Both were designed specifically for karst regions. However, all three indices measure vulnerability, whereas the KDI attempts to determine the degree of human impact; that is, what has actually happened, rather than what could happen in the future.

The application of the KDI by Van Beynen et al., (2007) in the Hillsborough County, Florida, allowed its refinement and highlighted those environmental aspects in need of remediation, such as soil compaction, deforestation, disturbance of archaeological sites, and the expanding urban footprint. Several minor issues arose while applying it: the need for broader indicator descriptions that encompass a variety of scenarios; the need for a revised water quality indicator; inadequate data on sinkholes; lack of data on species richness and species population density. North et al., (2009) assessed and compared the utility of the KDI in west-central Florida and southeast Italy, and made further recommendations to refine the index, which included the modification of the total disturbance scores included in the original KDI. Some of the indicators used in this method are difficult to assess, and evaluators are obliged to report lack of data (LD), meaning that more research is needed in that particular field. This situation was also indicated in a research work carried out in Apulia (Italy), where typical Mediterranean problems are encountered (Calò and Parise, 2006). KDI was also applied by De Waele (2009) to karst areas of Sardinia (Italy), where he used a slightly modified version of the KDI. Instead of considering the environmental disturbances indicators used in the original method, this slightly modified index evaluates those disturbances causing the deterioration of the environmental attributes.

Given the increased awareness of the effects of human disturbance across many different karst landscapes with growing human populations, efforts have been made to reduce negative impacts and to promote sustainable development. The exact framework to achieve sustainability reflects the conflicts between ecological conservation and resource exploitation, and lack of political will. Evidently, it is necessary to develop quantitative measures and plans that help facilitate a sustainable society (Brinkmann & Garren, 2011). To date, very little work has been done to create sustainability indices for specific environments. Recently, Van Beynen et al. (2012) created the Karst Sustainability Index (KSI) as the standardized metrics of sustainable development practices in karst settings. This index adopts pre-established objectives to determine the global sustainability of a given karstic region. Indicators are designed to incorporate common sustainability measures for the three domains of social, environmental and economic resources usage.

In an attempt to attract the scientific world's attention to the need for sustainable management in karst settings, including the most fragile and vulnerable environments in the world, a study was undertaken in the valuable La Serreta endokarst by applying the KSI to assess both this enclave's degree of sustainability and the applicability of KSI indicators.

STUDY AREA

La Serreta endokarst is found in the Los Almadenes karst (Fig. 1) which opens out and makes good used of a tectonic fault with massive cut superimposed dolomite and limestone strata in the Murcian municipal areas of Cieza and Calasparra (SE Spain). At Los Almadenes, the Segura River has created a canyon with heights approaching 120 m where canyon walls are practically vertical. The surroundings, including the adjoining landscape called Los Losares, contain caves, chasms and rock shelters. The interiors of many of these caves depict Palaeolithic and post-Palaeolithic cave art. In the same area, several archaeological sites have been documented (Montes, 1996; Salmerón, 1999) which date back to between the Lower Palaeolithic and the Islamic Middle Ages.

La Serreta cave-chasm, which is next to the upper edge of the aforementioned canyon, currently has two entrances (Fig. 1): one is a 16 meter-high chasm which, today, can be entered via a metal stairway built in 1990 by the Regional Historical Heritage Service. The other is the main cave opening which faces southwest and opens out into the left canyon wall (Salmerón, 1999).



Fig. 1. A panoramic view of the Los Almadenes Karst. La Serreta endokarst can be entered either through an opening in the roof by means of a crack (dashed arrow) or onto Los Almadenes canyon (solid arrow).

LA SERRETA ENDOKARST: A HISTORIC OVERVIEW

Cave art

Inside this cave (Fig. 2), 50 figures of post-Paleolithic cave art, commonly termed Schematic, and which include some figures of a semi-naturalistic style (Salmerón, 1999), are distributed over two panels. Panel I (Fig. 3) is located on the northern wall of the cave entry. The purely schematic representations show several human figures in the shape of a Greek *phi*, an ancoriform, a cruciform, two large polylobular figures, other human sketches and three pectiniform four-legged animals (Mateo-Saura, 1996). The semi-naturalistic representations of this panel showed two archers pursuing a herd of horses arranged on a pyramidal structure, whose vertex is crowned by a stud horse, as its exclusive sexual characterization depicts.

Panel II (Fig. 4) is located on the wall in front of Panel I, but is set back more deeply into the cave. On it, are several figures of a strictly schematic style. At the top, an idol of an ancoriform head and a body in *phi* was discovered. The whole figure presents a series of short perpendicular strokes around its silhouette, as if to depict the rays of its supernatural power. Lower down, five human schematic figures can be seen, among which one polylobular form and two cruciforms stand out (Mateo-Saura, 1996).

Neolithic occupation

La Serreta endokarst is considered one of the most interesting Mediterranean Neolithic sites, not only for its excellent state of conservation, but also for the uniqueness of some of the activities carried out at the site by some of the first farmers and shepherds of the region, somewhere between the sixth and ninth millenium BC (Salmerón, 1999).

To the extreme south of the cave two silos have been dug in the sterile terra rossa soil which made up the oldest Neolithic floor of this cave. These silos were filled with ceramic materials, boatshaped sandstone hand mills, the handles of these mills, a pendant made from a bone cane, and lithic industrial materials sculptured in flint, quartzite and limestone (Fig. 5). Yet, the most important finding inside the silos was a large group of wheat and barley seeds, which has been documented (Sánchez-Martínez, 1996).

Late Roman occupation

Roman occupation in the cave took place in two phases: the second half of the third century; the second phase of occupation may date back to the first years of 400 AD. The two Roman constructions are superimposed (Fig. 6). The older is formed by a floor made up of irregular large-sized sandstone slabs outlining a rectangular-shaped room, which would have measured approximately $5 \ge 2.5$ m inside. This floor was surrounded by a stone skirting board upon which an adobe wall was erected (Salmerón, 1999). Inside the second construction, the decomposing adobe served as a new floor of an inner room, which roughly measured $3 \ge 2.5$ m. Next to this main room,



Fig. 2. Geographical situation and map of La Serreta endokarst with cave paintings (panels I and II), archaeological remains (Roman houses) and platforms connected by stairways which overcome the sharp slope there which ends in the viewpoint platform at the terminus of the route (map: M. Fonseca).

another room was built, measuring approximately 1.5 x 1.5 m. It was paved with small sandstone slabs, whose south wall was formed by the cave itself. There is a lintel made from quadrangular sandstone slabs over the entrance to this room (Salmerón, 1999). The archaeological documents mention the existence of roofs partially covered by imbrex during both construction phases (Salmerón, 1999). This was a necessary measure to protect dwellers from the rain, which could have entered the main cave opening and filtered through the chasm.



Fig. 3. Wall painting with panel I in the La Serreta endokarst. The effect of algal growth: disintegration because of chasmoendolithic growth (arrow).

The fact that Roman constructions are rarely located inside a cave made us consider the possibility of its cultural use. Nonetheless, lack of clearly votive material and the existence of a rubbish dump outside the construction, suggest that the two successive constructions were chiefly employed as a dwelling place of a person who, among other activities, carried



Fig. 4. Wall painting with panel II in the studied La Serreta endokarst showing the Idol. Algal growth action: Epilithic communities totally cover the painting (photo by J. Salmerón).



Fig. 5. Fragments of limestone bracelets. Neolithic (photo by J. Salmerón).

out medical practices. Three bronze utensils for this use were found, two of which were used for preparing drugs. Such practices could be related to the nearby spring called El Borbotón, and its sulphureous and thermal waters.

Deterioration of cave paintings and archaeological remains

Algae grew on the ceiling and walls in La Serreta endokarst, occasionally covering the painting and archaeological remains, resulting in an unsightly appearance and chromatic changes. The algal flora in La Serreta cave-chasm has been studied (Asencio & Aboal, 2000a) in an attempt to diagnose the level of deterioration that the paintings and archaeological remains have undergone. Epilithic and chasmoendolithic algal growth has been observed, which contributed to the biodeterioration of the paintings and archaeological remains (Asencio & Aboal, 2001). The epilithic species observed belonged to Bacillariophyceae, Chlorophyceae, Cyanophyceae, and Xanthophyceae, the chasmoendolithic species were Bacillariophyceae, Cyanophyceae, and Xanthophyceae.

Occasionally, some species may change from epilithic to endolithic depending on environmental conditions. This occurred with *Chroococcidiopsis kashaii*, *Hantzschia amphioxys*, *Leptolyngbya perforans*, *Neidium binodis*



Fig. 6. Two superimposed Roman constructions inside the La Serreta endokarst. The older of the two (solid arrow) is formed by a rectangular-shaped room, approximately 5 x 2.5 m. The second construction (dashed arrow) has a main room, 3×2.5 m, and next to it, there is a room of approximately 1.5×1.5 m (photo by J. Salmerón).

and *Symphyonema cavernicolum* (Fig. 7) in panel I and II of Serreta, where they were chasmoendolithic in Panel I and epilithic in Panel II (Asencio et al., 1996). A study of the microenvironment of both panels throughout the year showed that temperature and relative humidity were similar, while photosynthetically active radiation (PAR) was very high in panel I where algae grew chasmoendolithically to protect against intense radiation (Asencio & Aboal, 2000b).

The action of epilithic communities on the rock surface resulted in the formation of crusts, which partially or totally covered the paintings and archaeological remains, as on the so-called Serreta Idol (Fig. 4). Chasmoendolithic algae had settled in any fissure, thus damaging the rock, which is crumbling (Fig. 3), and endangering any nearby painting and archaeological remains (Asencio & Aboal, 2001). The observed epilithic growth, which was more abundant than endolithic growth, suggests greater lithogenic (rock formation through precipitation) than litholithic (rock degradation and destruction) activity of a biological origin.

This first diagnosis should be followed up by research into the best way of protecting the cave paintings and archaeological remains from damage caused by microalgal growth. There were plans to apply treatments which have already been attempted in other places, such as radiation treatment on some frescoes (Albertano, 2012), sodium or calcium hypochlorite used in some caves (Iliopoulou-Georgoudaki et al., 1993) and formol used on some cave paintings (Bastian & Alabouvette, 2009). Efficacy of these treatments has been demonstrated with epilithic organisms, but little is known about their effect on endolithic algae, although it is assumed that they are protected within the rock from the action of biocides (Romero-Noguera et al., 2008). Algal growth should be aggressively removed since it was responsible for much of the degradation and deterioration of many cave paintings and monuments of historical importance (Macedo et al., 2009).

PRESENT-DAY SITUATION IN LA SERRETA ENDOKARST

Sustainable development model

For the purpose of enhancing the development of La Serreta endokarst and of improving the relationship between mankind and nature by conserving natural resources to help make them and their sustainable use compatible, and to maintain cultural values, an initiative was started at La Serreta as a pilot test that



Fig. 7. Light micrographs [scale bar: 10 $\mu\text{m}]$ of Symphyonema cavernicolum.

involved experimenting with sustainable development models in karstic environments.

On the 40th anniversary of its discovery, La Serreta cave-chasm was adapted for public use with the intention of showing visitors the artifacts within the cave. The adopted solution intended to minimize contact with the valuables inside the cave while also making full use of the magnificent interpretative conditions in this unique place. Part of the effort was to highlight the spectacular views over the Los Almadenes canyon, where the River Segura flowed, which is now a viewpoint over the void.

Only two construction materials were employed, steel and wood, which were in keeping with the stone surroundings and allowed the wonderful cave paintings and the remains of the Roman village to be viewed. This has been achieved by platforms connected by stairways, to avoid the steep slope terminating there at the viewpoint platform at the end of the route (Fonseca, personal communication) (Fig. 2). Signs were designed to form part of the architectural ensemble. Access to the ensemble was considered to take the form of a closed box (Fig. 8) which, in turn, protects and identifies the place when open. From this element, several metal stairways descend to the cave bottom, where wooden stairways, erected upon the rock layer run to the most relevant areas (Fonseca, personal communication). This task included solar panels to provide self-sufficient lighting in the darkest places on the route (Fig. 8).

Application of the Karst Sustainability Index to La Serreta endokarst

The KSI uses predetermined targets to ascertain the overall sustainability of a karst region. Indicators are designed to incorporate common measures of sustainability for the three domains of social, environmental, and economic resource use; each possesses a subset of indicators and target levels that determine progress toward sustainability (Van Beynen et al., 2012). The time frame within which these targets are achieved depends on the capacity of the organisation with jurisdiction over the karst region. This



Fig. 8. (a) Access to the La Serreta endokarst (arrow) considered to resemble a closed box (b) which, in turn, protects and identifies the place when it is open (c).

capacity may be affected by the current environmental state under the control of this organisation's jurisdiction. The KSI provides a robust measure of sustainability (Van Beynen et al., 2012). There are various scales to which this index can be applied, including large areas, such as states or counties, which encompass an entire karst area, as well as small karst watersheds. Applications on both scales offer advantages and disadvantages. The major advantage of working at the watershed level, as with La Serreta endokarst, is that it allows the collection of very detailed local data and information; this provides more accuracy in sustainability assessments. Another advantage is to keep building the study area outwardly from a single watershed and to allow comparative analyses.

The results are shown in Table 1. Progress towards the KSI targets for the La Serreta endokarst was measured between 1996 and 2011, or at least during the period for which data were available. Data for the equity and environmental justice measures in the social domain, such as ownership, employment, access and displacement, can be acquired only by local data collection, policy assessment and interviews. However, information on karst education as part of school curricula, education centers and tourist locations can be acquired from school officials, education centers and cave managers. The social domain component (Table 1) demonstrates the most effective efforts towards sustainability in relation to the enclave. La Serreta cave-chasm, located within Cieza holdings, is publicly and locally owned, as are the rest of the caves in the Los Almadenes karst. Karst-related employment is based locally (CARM, 2005-2011). There are no restrictions in the La Serreta endokarst to the water pumped from the karst aquifer. While displacement of a population segment may be commonplace in developing countries, and the access to karst resources that indigenous people have may be restricted, these two indicators are not applicable to La Serreta endokarst. The entire school population in the Cieza municipality has received education on the karst landscape. Several schools, whose curricula included an environmental focus on the Mediterranean region, have been visited by graduates from the University of Murcia for talks on karst-related matters (Observatorio de Desarrollo Rural, Local y Empleo, 2010). The local government has produced brochures and provided information on its websites about the sustainable use of local karst resources (Ayuntamiento de Cieza, 2011).

The environmental domain has a number of data sources. Local or regional government agencies are a source of information on forests, protected areas, riparian zones and the monitoring of various water quality indicators. They are responsible for enforcing local and national environmental regulations. Departments of Environmental Protection or Conservation often measure the environmental status for those areas under their control. In addition, all these agencies may have GIS map files and spatial data, which may prove invaluable to illustrate the changes that have taken place in their regions. Cavers and cave organizations possess a significant amount of information that cannot be ignored, particularly Table 1. The three principal domains (social, environmental and economic resource use) of the Karst Sustainability Index (KSI). The KSI scores in the La Serreta endokarst.

Indicator	Target (%)	Progress Towards Target
Social Domain		
S1. Local ownership, private or public, of caves and springs	>80	Achieved
S2. Locals employed in karst related jobs	>80	Achieved
S3. Equitable access for the population to karst water resources	100	Achieved
S4. Percentage of population displaced by the urbanization of karst landscape	<5	N/A
S5. Indigenous people's access to karst resources	100	N/A
S6. Percentage of schools offering karst education in their curriculum	100	Achieved
S7. Percentage of karst-related tourist facilities offering informal education	100	Achieved
S8. Local governments offering karst-related information on websites or through publications	100	Achieved
Environmental Domain		
En1. Amount of karst area forested or with native vegetation	<u>↑</u> 20	Stable
En2. Amount of karst designated as protected	<u>↑</u> 20	Increasing
En3. Biodiversity of species in a karst environment	Stable	Stable
En4. Riparian zones around hydrological input sources to karst groundwater	>75	Increasing
En5. Number of impaired springs measured by biological or water quality indicators	↓20	N/A
En6. Percentage of monitored water supply springs and wells	100	N/A
En7. Current landfills preventing groundwater contamination	100	Achieved
En8. Collection of sewage from all the homes in urban areas	100	Achieved
En9. Tertiary treatment of urban wastewater	100	Achieved
En10. Monitoring the condition of heavily used caves	100	Achieved
En11. Enforcement of local regulations	100	Achieved
Economic Domain (Resource Use)		
Ec1. Abandoned commercial quarries or mines that have been reclaimed	100	N/A
Ec2. Water extraction from aquifers and springs	Stable	N/A
Ec3. Increase in agricultural water efficiency (value in €/consumption)	<u>↑</u> 20	N/A
Ec4. Area of urbanization and roads	Stable	Stable
Ec5. Sustainable forestry on the karst landscape	100	Stable
Ec6. Number of eco-tourism ventures related to the karst landscape	↑20	Increasing

on cave management plans and eco-tourist activities. The La Serreta endokarst study confirms that these data sources are essential and that they have often been readily available in regional management plans because agencies from the Comunidad Autónoma de la Región de Murcia, such as the Consejería Agricultura, Agua y Medioambiente, have also collected useful data. In addition, scientific research is another important source of environmental data to assess the state of certain aspects of the karst environment. For many karst regions, the environmental domain poses the greatest challenge to achieve sustainability (Van Beynen et al., 2012). Table 1 shows how the La Serreta endokarst has a somewhat mixed record when it comes to sustainability. Over a 12-year period from 1996 to 2008, the amount of karst area with native vegetation remained stable (Gual, 2009). The need to protect the La Serreta endokarst, which has been a World Heritage Site since 1998, has resulted in land acquisition by local government agencies (Ayuntamiento de Cieza, 2006). For example, in 1992, the Los Almadenes karst was declared a protected area by Law 4/92 of the Territorial and Protection Bylaws of the Murcia Region, covering 116 ha. In 2006, the Comunidad Autónoma de la Región de Murcia was authorized to extend the construction of an interpretation center to five areas (CARM, 2008-2010). Today, 80% has been completed. Its objective, with a budget of 4.1 million euros, was to make this setting sustainable, with all its highly valuable landscape, botanical, faunistic, geological and archaeological values (Ministerio de Hacienda y Administraciones Públicas, 2011). Therefore, the protected karst areas have increased as a result of this process. The indicator pertaining to riparian zones is directly related to this increase in acquired lands. The stable amount of karst area with native vegetation in the La Serreta endokarst and this increase in protected land pose a question as to determining how biodiversity is affected. Biodiversity remain stable despite the protected surface increasing owing to vegetation being the same throughout the area (CARM, 2010). The local caves in the Los Almadenes karst are relatively undisturbed given lack of public access, and those that are visited such as La Serreta which, since its discovery receives 1000 visitors every year, have cave management plans devised by the municipality venture known as "Consorcio turístico del karst de los Almadenes" (Ayuntamiento de Cieza, 2011). Although springs measured by biological or water quality indicators, as well as monitored water-supply springs and wells, can provide very important data, these two indicators are not applicable to the La Serreta endokarst. The modern landfills design safeguards ground water, and residential wastewater is collected and treated properly in an oxidation pond system (CARM, 2010). Finally, the enforcement of regulations to protect the karst landscape is measured by fines. Levied fines have increased by 10% (CARM, 2008-2010).

Information economic or resource for use indicators generally originates from local, regional or national governmental organizations. Data on water consumption and on waste collection and treatment are typically collected by local municipalities or waste and water management organizations. Regulations that influence land use and urban development can be assessed at local, regional and national levels. For the La Serreta endokarst, these data were created by the CARM (2008-2010) and by groups at regional universities, such us Murcia (Observatorio de Desarrollo Rural, Local y Empleo, 2010). The quarries and mines factor was not applied to the economic domain because no such destructive activities and important sources of income are found in the La Serreta endokarst. For centuries, cereals and pasturelands have been the predominant agriculture in the area. For this reason, agricultural water efficiency is not applicable in the economic domain. Although water extraction from aquifers and springs can provide very important data, this indicator is not applicable to the La Serreta endokarst. In relation to the area and its urban development and roads, the few and isolated residential buildings are basically detached homes used as a second residency. They are connected by narrow country lanes, into which a bicycle

lane is soon to be incorporated (Ayuntamiento de Cieza, 2011). Changes in the urban development of an area are often an indicator of economic growth. In the La Serreta endokarst, no further changes have been made since its urban development, and its road system is stable. This indicates the sustainable use of this karst landscape because the area has not increased from 1996 to 2010 (Observatorio de Desarrollo Rural, Local y Empleo, 2010). Logging is another economic activity that proves important to a local economy. In 2005, the first rural tourism firm was set up in Cieza, and today there are seven firms actively working (CARM, 2011a). They are in charge of restoring country homes and must respect the traditional popular architecture, structure and layout of the rural farmhouses and ranches in the area, inhabited by some 10 persons. This sector is a significant component of employment in the La Serreta endokarst.

In addition, use of native vegetation, particularly Stipa tenacissima, has been stable and remains sustainable (Observatorio de Desarrollo Rural, Local y Empleo, 2010). From this autochthonous species, which covers most of the La Serreta endokarst surface, esparto grass, a natural fiber, is obtained, and it is used to make local crafts, and is also in buildings (CARM, 2009a). Esparto grass production has formed an important part of the local economy and, even today, it still provides work, as the esparto grass museum reveals, which was opened in 2001 (CARM, 2009b). Moreover, karst-related tourist attractions include a series of artistic, cultural and sports activities. They include visits to the La Serreta endokarst to view its cave paintings, archaeological remains, as well as its spectacular views over the Los Almadenes canyon, where the Segura River flows. Currently, there are four types of sporting ventures available: trekking, climbing, speleology and riding in a hot air balloon (CARM, 2011b). Finally, tourism has been a significant source of income to the La Serreta cave-chasm, and the karst landscape has greatly contributed to this sector (Observatorio de Desarrollo Rural, Local y Empleo, 2010). All the above sustainable eco-tourist entities evidence the increasing number of such ventures in recent years (CARM, 2005-2010).

DISCUSSION

Karst Sustainability Index was applied to La Serreta endokarst, which took into account the three environmental sustainability pillars employed evaluate karst landscapes: social equity, to environmental values and economic development. Several specific variables are measured in all three domains, which can be used by KSI to provide an assessment framework in karst lands. It was quite apparent that the La Serreta endokarst has met nearly all its sustainability targets set by the KSI for the social domain, where education and the direct involvement of anybody living in karst territories has proven crucial (De Waele, 2010). The enclave was also making progress in the environmental domain, with only two indicators showing no improvement or worse conditions over the measured time frame. Creating environmental awareness to safeguard the karst

and its resources was the first step in the process of creating sustainable development in these sensitive environments (De Waele et al., 2011). In the economic domain, much progress remained as none of the KSI targets had been achieved. Consequently, the overall KSI rating for the La Serreta endokarst is that the enclave is progressing towards the sustainable development target.

The sustainability of La Serreta endokarst was measured with an index that sets targets for government bodies, and which takes into account issues of equity, environment and economic development. One difficult measure was enforcement. It has been acknowledged that while the simple creation of regulations protecting karst was laudable, their enforcement was just as important (Van Beynen et al., 2012). However, there was not a single enforcement method to measure. Fines, loss of access and restoration requirements were all possible methods. In addition, assessing enforcement within a sustainability index is difficult. As fines have increased over time, enforcement is considered to be improving. One possible limitation of any index is its truth in reporting and its uniform application. Company and government officials may feel it is more important to give the impression of sustainable operations and environmental stewardship. As such, third party evaluations and verifications may prove appropriate, which is in agreement with Van Beynen et al. (2012).

The data required to score the indicators became available while collecting data on the La Serreta endokarst to apply the KSI, except for some sustainable forestry changes taking place in the region. The related economic indicator values allowed a justifiable assumption to be made of the forestry status in the study area. Well-funded regional agencies and some local university studies provided all the data in the reports, which are available to the public. Therefore, it was only necessary to find these reports and to collect data.

We considered the contributions of various karstrelated industries to the local economy to be economic indicators of the KSI. However, collecting these data at municipal levels proved very difficult. For example, when attempting to collect information on aquifer and spring water extractions, we found data only at the regional level or for the entire company's operations, which extended beyond the La Serreta endokarst area. It was not possible to find what we needed for the specific karst region under study.

As with any index, it is not possible to include all sustainability aspects in the KSI. Therefore, one limitation of this index may be lack of indicators characterizing the tourist endokarst. It is well-known that human influence in caves alters the dynamic equilibrium of the natural environment. This imbalance has serious effects on the cave atmosphere, including raised temperature, lower relative humidity and higher CO_2 concentration. The CO_2 exhaled by visitors is far from being the only factor responsible for degradation found in the cave deposits. The new environmental conditions generated by human intervention in this fragile system, such as higher temperatures and lighting systems, will encourage the colonization and spread of numerous microorganisms in various cave sectors, where algal activity is leaving its mark on the substrate in the form of weathering, algal pits, holes and etching. The general effects of the two environments are not independent; instead, one system changes because air implies direct or indirect changes in the other system. In La Serreta endokarst, the result of this chain of processes may lead to the deterioration by epilithic and chasmoendolithic algal growth of cave paintings and archaeological remains, which are the main attraction of the cave, along with the karstic landscape hosting them.

CONCLUSIONS

The La Serreta endokarst has met almost all the sustainability targets set by the Karst Sustainability Index for the social domain. The enclave was also making progress in the environmental domain, with only two of the eleven indicators showing no improvement or worse conditions within the measured time frame. In the economic domain, much progress needs to be made because all the KSI targets remain to be achieved. Consequently, the overall KSI rating for the La Serreta endokarst is that the enclave was progressing toward the sustainable development target. Although the index has its limitations, in La Serreta endokarst study reveals that they are minimal.

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